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Application of ground energy in ventilation

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DESCRIPTION

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Abstract

One of the main goals of this research work was to evaluate the effectiveness of a system based on the direct utilization of ground energy. The effectiveness is estimated and compared to more traditional systems. The effectiveness is assessed only in the aspects of recovering and spending heat energy.

The observed systems have elements such as heating, cooling coils and heat recovery units as most of the traditional systems. The peculiarity of such systems is that one of coils for heating or cooling is connected to a ground loop, not to more popular energy sources as a district heat network or others. Thus they allow transferring energy from the ground to the air in case of winter air heating or transfer energy from the air to the ground in the case of summer air cooling. It should also be noted that in such systems there is no heat pump between the ground loop and the air coil. A heat carrier circulates directly between the ground loops and the air coil without the transformation of energy, which could take place in the case of installed heat pump.

The operation of the system is analysed based on the available data from the automation system of an air handling unit. The air handling unit is located in an office building (N-building), in the campus of Mikkeli University of Applied Sciences. Available data is for the winter 2012-2013.

The result of the research is that for the winter period such a system based on the utilization of the ground energy is not so effective as more common systems based only on a heat recovery unit in energetical aspects. The energy gain is achieved only if it is possible to replace the system in the case with a system based only on a heat recovery unit with the temperature ratio less than 0,65. In practice temperature ratios are 0,7-0,8. Ensuring average temperature ratio for the winter period of the heat recovery unit in a system based only on this heat recovery unit, at least 0,65, provides no energy profits compared to the system in this case. Ensuring higher values of temperature ratio results in ineffectiveness of the system in the case compared to more common systems. Aspects of additional expenditures for ground works, more equipment, running costs are to be taken also into account.

Subject headings, (keywords)

Ventilation, ground energy, thermal energy, ground heat exchanger, ground-to-air, preheating and precooling of air by ground water

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CONTENTS

NOMENCLATURE

c_p	specific air heat capacity, 1,2 (kJ/(kg·K))
Q_{GC}	utilized energy in ground-to-air coil (kW·h)
Q_{HC}	utilized energy in heating coil (kW·h)
Q'_{HC}	possible utilized energy in heating coil (kW·h)
Q''_{HC}	corrected possible utilized energy in heating coil (kW·h)
Q_{HR}	utilized energy in heat recovery unit (kW·h)
Q'_{HR}	possible utilized energy in heat recovery unit (kW·h)
Q''_{HR}	corrected possible utilized energy in heat recovery unit (kW·h)
Q_{rec}	total recovered energy (kW·h)
q_{ve}	exhaust air volume flow rate (l/s)
q_{vs}	supply air volume flow rate (l/s)
t_{eHR}	exhaust air temperature after heat recovery unit (°C)
t_{ex}	exhaust air temperature before heat recovery unit (°C)
t_{GC}	supply air temperature after ground-to-air coil (°C)
t_{out}	outdoor air temperature (°C)
t_s	supply air temperature (°C)
t'_s	corrected supply air temperature (°C)
t_{sHR}	supply air temperature after heat recovery unit (°C)
t'_{sHR}	supply air temperature after heat recovery unit in virtual AHU (°C)
t''_{sHR}	corrected supple air temperature after heat recovery unit in virtual AHU (°C)
η'_e	ensured exhaust air temperature ration
η''_e	corrected ensured exhaust air temperature ratio
η'_s	ensured supply air temperature ratio
η''_s	corrected supply air temperature ration
ρ	density of air, 1,2 (kg/m³)

1 INTRODUCTION

The price of energy is becoming higher and higher all the time. During the lifecycle of any building the share of the energy used for heating, ventilation and another purposes is quite significant.

There are some ways of reducing energy consumption: proper systems design, utilizing energy-efficient materials and equipment, utilizing energy extracted from renewable energy sources, and so on. All those give a possibility for a designer to make an energy-efficient system and for customers save energy.

Energy-efficient system design means low heat losses, making a system more flexible and rational. For example, the use of more energy efficient insulating material saves energy due to energy losses through building envelope. Similarly the use of equipment with higher rates of coefficient of performance and lower power demand gives us a possibility to save energy.

Another way to reduce the energy consumption is utilizing available renewable or non-renewable energy. This could be implemented by means of, for example, energy recovery — extraction energy from extract air which will be uselessly discharged into the atmosphere. In the same way, energy could be extracted from discharged sewer water or utilized water after technological processes. Apart from the energy recovery, it is possible to obtain renewable energy, for example, solar energy, wind energy or ground energy. They are so-called low potential energy.

High-technological and quite complicated design of systems of energy-efficient applications entail high running costs and the necessity of high-qualified maintenance. In spite of that, those systems are quite advantageous. These systems are especially reasonable to design and arrange in areas where energy costs are high.

All those affects the running costs by lowering it. So, the designer and especially the consumer are pleased to have a more economical system. The influence over environment is also milder — CO_2 emissions are reduced. This is achieved by increasing the share of energy extracted from the renewable sources and lowering the share of energy generated by burning fossil fuels. Moreover it reduces the malign effect over the environment mainly by lowering the rates of producing CO_2 during the process of generation energy if fossil fuels are used.

2 AIMS

The research question of this bachelor's thesis is to pay special attention mainly to utilizing ground energy in ventilation. Firstly an overview of all possible ways and means to extract and utilize ground energy will be given. This part is based mainly on literature review. All possible types of systems for extracting heat from the ground will be overviewed in this part: advantages and disadvantages of every type, their scopes and fields of applications, required and desired materials and equipment, ways for increasing energy efficiency of each of them.

After this, attention will be paid to a certain study case, and attention is focused on low-temperature energy sources. An investigation of actual effectiveness of ground energy utilization basing on an air handling unit will be conducted. An attempt to compare this system with more traditional systems will also be made.

The certain study case is an air handling unit with some peculiarities in its construction and operational modes. Generally, there are two specific cases in operation of the air handling unit: summer and winter. The summer state of the system means that intake air is being cooled in the coil connected to the ground loop. Vice versa the winter state of the system utilizes heat from the ground to warm up intake air for some extent.

3 METHODS

In general attention should be paid for analyzing and describing the whole system in two cases (winter and summer). In this bachelor thesis the analysis will be given only to the winter case due to the available data only for the winter period.

3.1 Automation system of the air handling unit

The analysis will be based on an available data obtained from an automation system of the air handling unit. These obtained data are temperatures at certain measured temperatures of air (e.g. outdoor temperature, temperature after first coil etc.). Data is measured by installed on-sire sensors. Based on this data, it is possible to estimate how much energy is extracted from the ground and how much energy is recovered in the certain air handling system. In this work available data and operational process of the air handling unit for the period from 13 December 2012 until 1 February 2013 will be analyzed.

3.2 Virtual air handling unit

For analyzing and comparing obtained actual data, the notion of virtual air handling unit is brought into this work. Virtual air handling unit is similar to the original one except the most peculiar part — heating coil connected to the ground loop. Removing some parts from the air handling unit in case imposes some constraints on the analysis, though calculations are based on the same initial data.

4 ENERGY IN THE GROUND

Geothermal energy is contained inside the ground — rocks and water filling free spaces in the ground. It is believed that the ultimate source of ground energy is radioactive decay. This type of energy is clean and sustainable. The resources of ground energy are from deepness close to the ground up to hot water and hot rock which is possible to find deeper. /1./

Geothermal energy has arisen from the heat collected within the Earth since the original formations of the planet, from radioactive decay of minerals, and from absorbed by surface solar radiation /2/. Heat energy is transferred from the depth of the Earth's crust by conduction and sometimes by convection from deep layers where magma is present. Different locations throughout the Earth have different ground temperatures because of the different heat transfer intensity due to the different composition of soil.

The normal gradient of ground temperature is nearly from 10 to 50 Celsius degrees per one kilometer. /3./

Economic feasibility of the geothermal use depends on three major things: resource, application, and the way how this resource and this application are connected together. In any geothermal system the expenses of operation are low, but primary investments are quite high. /3./ Probably the main problem in utilizing and extracting of ground energy is the way how to reach this energy. It is impossible to utilize much of the ground energy due to its great depths. Reachable energy is contained at some depth, thus requiring ground drilling and arranging boreholes, resulting in excessive costs for groundworks. /4./

The following characteristics affect the final costs of extraction and utilizing thermal energy: depth of resource, distance between heat source and utilizing place, water flow rate which can be gotten in a certain water well, source temperature and temperature drop, load size and factor (relation of the average loads and design loads), easiness of disposal and how long it is possible to utilize energy source. The temperature drop directly influences the power output since the flow rate of a well is limited. The composition of fluid should also be taken into account, because some special measures against aggressive fluids (if such are presented in ground) should be made for protecting the system. /3./

The soil temperature plays a major role in designing and maintaining a geothermal system. It is important to know and estimate the available temperature difference before choosing the type of a system and designing it. /5./

5 CLASSIFICATION OF GROUND ENERGY SOURCES

Usually geothermal resources of energy are broken down into three classes: high-temperature (> 150 °C), intermediate (90 — 150 °C) and low-temperature (< 50 °C). /3/. If the first two points require special utilization and are applicable for big groups of consumers (e.g. geothermal electricity and heat producing plants and nearby cities or factories), the energy from the third one can be extracted for the needs of a certain building or a group of buildings. Almost in all places around the world temperature of the ground deeper than 3 meters almost constant and varies from about 10 °C up to the 16 °C. /1./

Due to specific geological requirements, the first and the second groups are seldom adopted in designs. Usually low-temperature energy sources are used. The temperature of ground water is the most crucial characteristic which affects designing and planning of a system based on geothermal energy.

6 DERIVING ENERGY FROM THE GROUND

The possibility of utilizing the natural sources of energy, such as energy contained in ground waters, depends on the characteristics like the following ones: level of ground water, temperature of ground water, bacteriological and chemical compositions of ground water, water roughness and so on. /1./

There are three principal ways to derive and utilize ground energy in customers' systems. The first way is based on direct gathering and transporting ground water containing ground energy into the customer's system, where this water is treated and ground energy is summoned into the customer's system for further utilization. These systems are based on production and injection wells. The feature of these systems is that water circulates in an open loop.

The second way is utilizing different kinds of ground loops. The feature of this kind of systems is that water circulates on a closed loop.

The third way is utilizing numerous available nearby surface water bodies such as lakes, river, seas and so on. Operation principal of these systems can be based on either an open loop or a closed loop.

6.1 Deriving energy from aquifers by water wells

Aquifer is an underground reservoir containing ground water. This ground water is enclosed in an underground stratum such as sand, chalk layer or sandstone. /6./ The principal scheme of the system in two operational modes is presented in Figure 1.

Two modes are summer cooling and winter heating. During the first mode excessive heat in the building dissipates in the ground due to the temperature difference. The temperature of the ground is lower that indoor temperature, thus allowing to use energy from the ground for cooling. During the second mode temperatures of ground could be used in heating. This is possible, similarly, due to the temperature difference between the ground and, for example, low-temperature winter income air. Effectiveness can be raised also by adopting heat pumps.

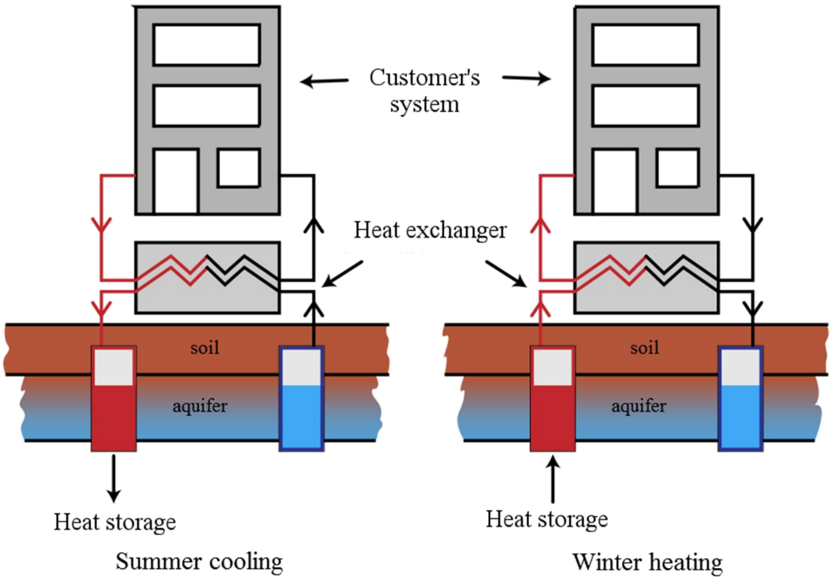


FIGURE 1. Operation of a system based on water wells deriving energy from an aquifer in different modes /7/

In this kind of systems geothermal energy is transferred by means of ground water. This water is collected from the ground and returned backwards by means of water wells. Drawn water is pumped by means of wellhead equipment through the distribution network. After disposal energy, derived from the ground by means of production wells, an energy-depleted heat carrier is returned into the geothermal system for recovering its primary state. It is possible to use thermal ground energy directly, but due to corrosion and scaling hazards it is more preferable to avoid the direct utilizing of geothermal energy by means of ground water. In this case, heat exchangers are usually used for separating customer’s systems from the natural geothermal system. Minerals presented in the geothermal water are transported alongside with the water right into the customer’s system without heat exchangers. Later when the temperature of water decreases, some minerals are going to be participated out of the water causing scaling and fouling of pipes, which reduces inner smoothness and increases pressure losses. /8./

6.2 Equipment for deriving energy from aquifer

Water wells

Water wells are divided into a production well and injection wells. In the first wells, water is collected from the ground and then its energy is transferred to the customer's system. Injection wells are needed for returning used water back to the ground for reinstating its original state and characteristics. /1./

If a geothermal reservoir is not large enough, the low temperature of returning water could cause lowering the temperature of the aquifer. The thermal interference of production and injection wells should be taken into account too. In addition close placing of production and injection wells will disturb the normal operation of the system based on the aquifer principle. /8./

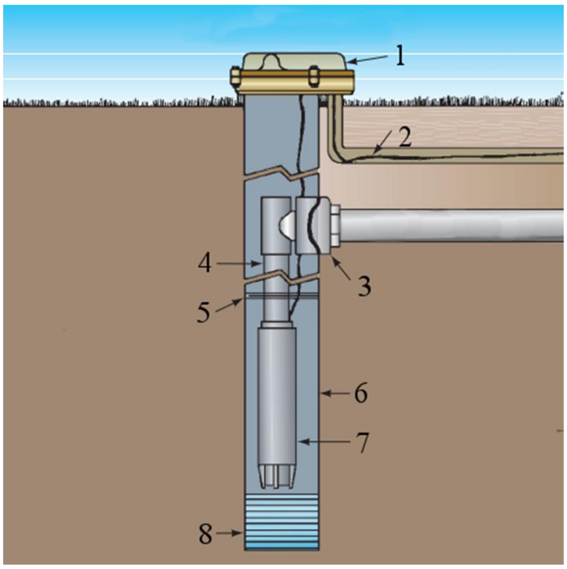
Production and injection wells are mainly evaluated by a specific capacity. This figure shows how much water infiltrates into the water well or exfiltrates back to the ground. Before designing the systems utilizing thermal energy of ground water, some flow tests should be carried out. It is possible to make a final design only after available flow test data and chemistry analysis of ground water are derived from the water well. The flow test provides us the actual specific capacity of the water well. Besides the chemistry analysis, physical and biological contamination analysis should be carried out. Because of extremely high corrosive nature (mainly due to oxygen, chloride ion, hydrogen ion, sulfides, carbon and ammonia species) those tests allow to make more thorough design of the system. /1./

Pumps for production water wells

Pumps are common equipment as in any other HVAC-application. Only the material of the equipment requires special consideration. Pumps are divided into two categories: lineshaft pumps and submersible pumps. For dimensioning a pump, some factors should be known by a designer, such as required pump head (elevation to be overcome), column friction (pressure losses for friction), and wellhead pressure.

The motor of a lineshaft pump is located on the ground, vertical shaft goes down to the well. In certain depths impellers are joined with the shaft. The pump is mounted at such depth where suitable net positive suction pressure is available during the operation of the unit. Net positive suction pressure shows the minimum pressure needed to prevent sucked fluid from boiling. There are two pump designs: open and closed. The first means that the shaft and bearing are freely in contact with ground water, the second means that there is a special casing protecting the shaft with bearings. Lineshaft pumps are more desirable at lesser depths.

Submersible pumps are located fully in water wells. They have some advantages over the lineshaft. Generally the exploitation of submersible pumps is cheaper, thus allowing us to have deeper wells compared to the lineshaft pumps. In Figure 2 a cross-section of a well with a submersible pump is shown.



1 — well cup,
2 — electric line,
3 — adapter,
4 — drop pipe,
5 — static water level,
6 — well casing,
7 — submersible pump,
8 — well screen.

FIGURE 2. Principal scheme of a water well with a submersible pump /9/

For any application of a pump, special attention should be paid to the composition of soil penetrated by a water well. If the water well is constituted from a rather big amount of sand, phenomenon of erosion can take place significantly narrowing the lifespan of the water well and threatening the normal operations of the pump. Usually water well flow requirements vary to a significant extent.

Heat exchangers

Heat exchangers are used to transfer energy from ground to the customer's part of the system by means of a geothermal part. The principal scheme of installing the heat exchanger between geothermal and customer's parts of the system is presented in Figure 3. As said before, heat exchangers also give the possibility to prevent direct contact between ground waters circulating through geothermal part of the system and the heat carrier in the customer's part of the system. Usually in ground energy applications, the following types of heat exchangers are used: plate, shell-and-tube and downhole. /10./ The first are two usually installed in a technical room or in special places like outdoor technical box. The difference between downhole heat exchanger and other types is that the first one has direct contact to the ground.

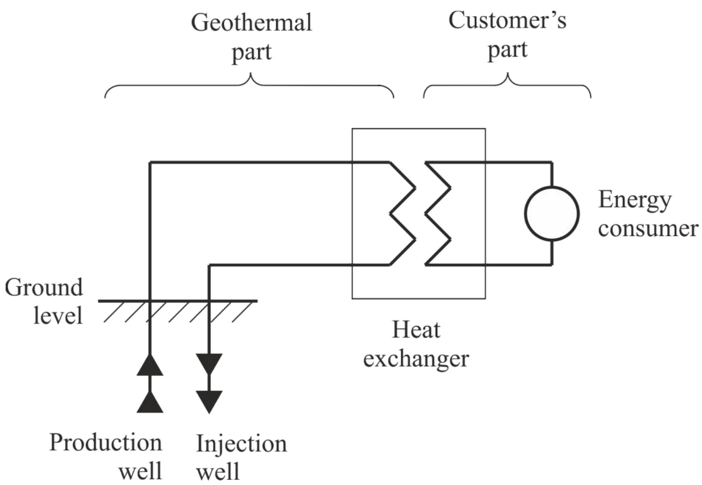


FIGURE 3. The heat exchanger in the system based on water wells

6.3 Deriving energy from the ground by ground loops

A downhole heat exchanger consists of buried pipes called here and further the ground loop. It could also be named differently, like a ground heat collector, brine pipe, pipe loop and so on. Ground loops can be subdivided into vertical and horizontal ones. Different ground loops are used in different projects. The type of utilized ground loops depends on the total performance of the system and local geological conditions. /3./

Pipes in ground loops can be connected either in a parallel way or in a series way. In the series connection fluid in ground loops has only one path to go through the loop, while in the parallel connection fluid is able to pass in two or more parallel paths. The selection of different types depends on the total energy load of a ground loop. Small-scale applications usually use either series or parallel-flow pattern, but big applications are usually referred to a parallel-flow pattern. /5./

At some certain depth, the temperature of the ground stops to change and becomes nearly constant throughout a year. This makes it possible to get the heat carrier with almost constant parameters a year round. /5./

Selecting the temperature of water coming from the ground loop is a critical issue in any geothermal system design. The closer value of dimensioning temperature to the actual ground temperature causes the higher performance of system, but all this leads to increasing of the ground loop in needed length. Widening temperature dimensioning range makes the ground loops cheaper and smaller, but these systems greatly lose in performance. /3./

The rate of heat transfer between the ground loop and surrounding substance is a major factor. The length of needed underground pipes depends on the thermal conductivity of the ground. In turn, arranging and maintaining costs depends on the pipe length. The thermal conductivity of a soil depends on moisture conditions and its makeup. Thus the same design of the ground loops depending mainly on dimensioning the ground loops can have different effectiveness and expenses depending on the local geological and climate conditions. /5./

The thermal interference is also desired to be taken into consideration during the design process. The thermal interference will decline the actual heat transfer effectiveness of each pipe in the ground loops, so some compensation coefficients need to be considered (for example, temperature penalty up to 3 °C when expected lifespan of a system is 10 years). The temperature penalty could be avoided by means of increasing distances between neighboring pipes, thus destroying thermal interference. /1./

The cost of ground loops accounts up to the half of the total cost of the systems based on ground loops, it is the most cumbersome part of a system for repairing or replacing /1/.

Vertical ground loops

Vertical ground loops are most effective because they require quite small ground surface spaces. The vertical ground loop contacts with soil in different depths, which means different temperature and thermal properties. The other advantage is the use of the smallest amount of pipes and spending less pumping energy. /1./ The principal scheme of a system with vertical ground loops is shown in Figure 4. Depicted black arrows show the direction of circulation, red arrows show the direction of heat transfer (cooling mode — heat dissipates in the ground).

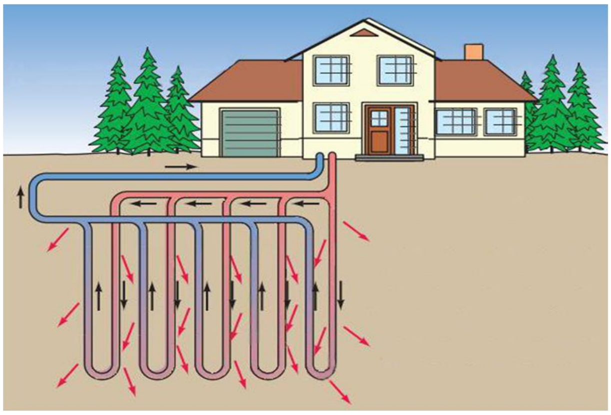


FIGURE 4. Principal scheme of a system based on vertical ground loops /9/

For installing vertical loops, vertical boreholes are required. Because of that, vertical ground loops require drilling equipment and processes costs which are usually significantly higher compared to those of horizontal trenching. There are three principal arrangements of a vertical ground loops: U-tube and concentric-tube configurations (Figure 5). Shown in the figure configurations are: 1 — single U-tube, 2 — double U-tube, 3 — single concentric tube, 4 — combined concentric tube. /5./

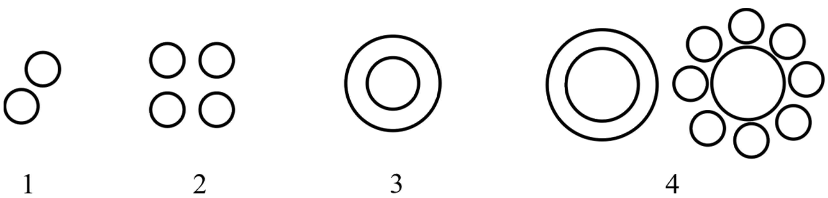


FIGURE 5. Different principal arrangements of vertical ground loops. Adopted from /11/

Design of vertical ground loops

Vertical ground loops are difficult to design mainly due to the absence of accurate information about soil content, moisture content and hydraulical conditions in a certain place. A lot of geological formations with different properties affect and make the system design more complicated. Nowadays the only way is to use empirically available data and simplified computing models to estimate different underground conditions. For example, one way is to take as granted the assumption that water well with pipes forming a ground loop is a cylindrical surface, the other one is based on a thermal response test. The main problem in designing and dimensioning of the ground loops is the absence of field data. /12./

Pipes in the vertical ground loops can be connected to each other whether in parallel or in series (single pipe ground loop). The cross-section of two main layouts of the vertical ground loops is shown in Figure 6.

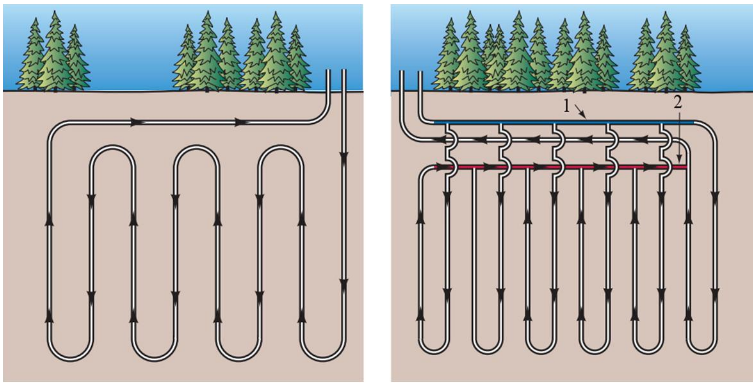


FIGURE 6. Cross-section of series (left) and parallel (right) connection of ground loops. 1 — supply pipe, 2 — return pipe. /9/

Horizontal ground loops

Compared to vertical ground loops, the main difference of horizontal ground loops is the necessity of bigger land areas. Horizontal ground loops are placed in narrow and shallow trenches. There are three main types of horizontal ground loops: single-pipe, multi-pipe and spiral. Horizontal ground loops are typically cheaper than vertical mainly due to simpler groundwork. /3./

Single-pipe means one pipe in one trench forming one solid long loop. The principal scheme of this type of the system is presented in the Figure 7. Black arrows show the direction of circulation, red arrows show the direction of heat transfer. The depicted mode represents the heating mode — heat dissipates inside a building, the ground is being cooled.

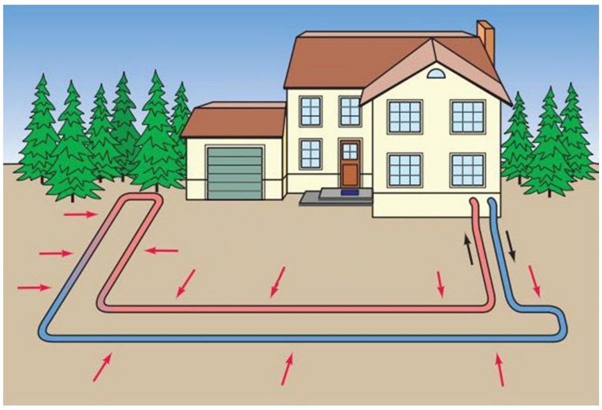


FIGURE 7. System based on the single-pipe horizontal ground loop /9/

A horizontal system formed by means on a multi-pipe ground loops is presented in the Figure 8. The multi-pipe system consists of pipes of different configurations. Thus pipes can be connected to each other in the series or parallel way, depending on the particular design layout. One or more pipes can be placed in a trench also simultaneously. Black arrows in the Figure 8 show the direction of the circulation of heat carrier in the ground loops.

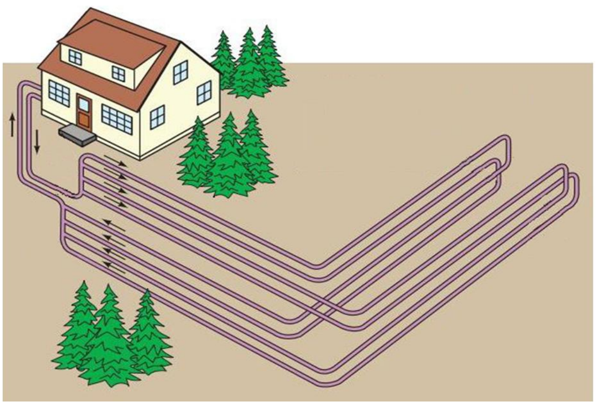


FIGURE 8. System based on horizontal multi-pipe ground loop /9/

The most favorable design is spiral, because less ground work is made for placing more ground loops, thus allowing a bigger heat exchanging surface. The spiral configuration is shown in the Figure 9. Black arrows in the picture show the direction of the circulation in ground loops.

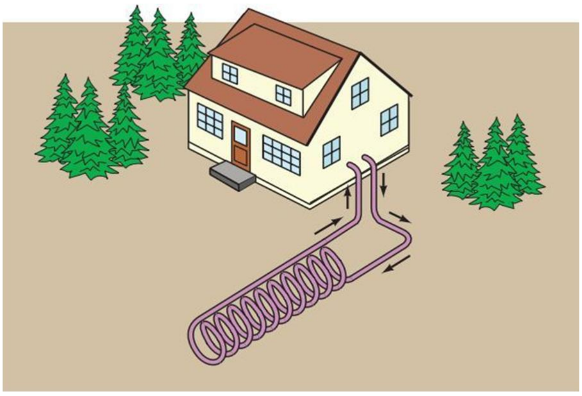


FIGURE 9. System based on the horizontal spiral ground loop. Black arrows show the direction of circulation /9/

Another obstacle in the application of horizontal ground loops is shallow depth, the ground at small shallowness depends too much on the outdoor temperature. The type of soil should also be closely considered: dryness especially in sandy soils and hilltop could significantly affect the final heat transfer efficiency because during summer those layers of soil could be just dried.

Design of horizontal ground loops

Theoretically the underground pipes of horizontal ground loops influence the ground temperature within the distance of 5 meters, but actual ground temperature is not influenced farther than one meter, thus allowing to bury pipes not very deep, in about 2 meters depth. The cheap installation is balanced by much bigger required areas of land and the danger of accidentally cutting under-the-ground-surface pipes. /13./

Parallel loops are more preferable than single or series loops (Figure 10, 1 — supply line, 2 — return pipe) mainly due to energy costs for pump operation: in the parallel connection of the pipes the smaller pump head is required. The same length of pipes connected in parallel requires much less power of a pump compared to the series connection. Parallel connection is also more reliable, and if damage of a pipe occurs, the only way is just to exclude the malign loop from the system. /3./

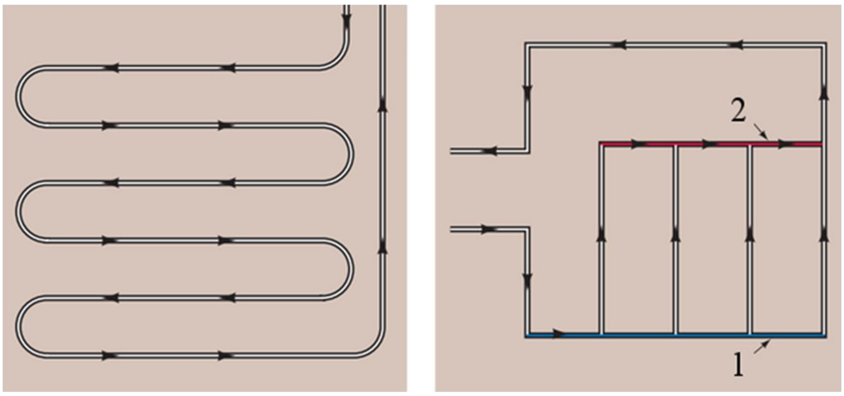


FIGURE 10. Series (left) and parallel (right) connection of ground loops /9/

Once horizontal ground loops are installed, the areas over it could not be used for any other purposes except just grass, parking lots or agricultural purposes. During the design of horizontal ground loops, it is also much easier to obtain needed data about ground, it could be observed and tested almost right in the construction place if it is necessary. /3./

Shallow horizontal ground loops laid from 1 up to 3 meters are subjected to seasonal temperature cycles due to solar radiation and transmission losses to the air close to the ground. These temperature cycles lag behind season cycles up to a few months, which should be considered in design and planning. /11./

6.4 Deriving energy from surface water

As was said before, the systems utilizing energy derived from surface water bodies can be either open looped or closed looped based on submersible loops. In the closed loop systems heat carrier circulates through a loop placed somewhere in natural water body, for example, in a river, lake or sea. Heat is taken away from water in a natural water body during the heating mode operation and transferred back to water in the cooling mode operation. /3./

The energy from the natural water body, ie energy contained in the heat carrier which goes through either the open or closed loop, is transferred into the customer's system by means of a heat exchanger. This heat exchanger could be on the ordinary heat exchanger like plate or shell-and-tube heat exchanger, and the purpose of this heat exchanger is to divide the customer's system from natural waters.

One of the main restrictions in the application of such systems is the characteristics of water body. The basic characteristics are temperature conditions. If the water body is too small or shallow, resulting temperature of circulating fluid fluctuates in a wide range, causing a decrease in the performance and effectiveness. /3./

The other major characteristic of a surface water body is a temperature pattern. Temperature patterns represent the dispersion of water temperatures throughout the year. The temperature patterns of lakes depend on factors such as the inflow and outflow rates or shallowness. The typical temperature patterns according to different seasons of a year are shown in the Figure 11. /5./

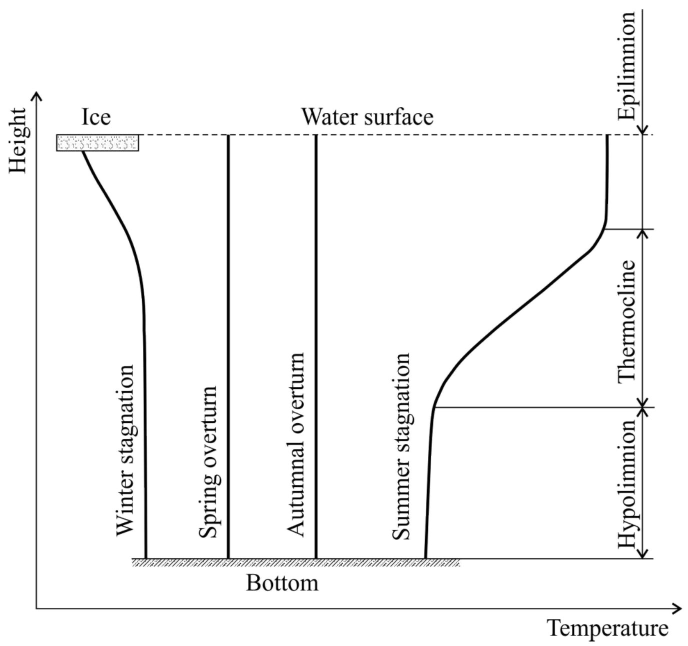


FIGURE 11. Temperature patterns in surface water bodies all the year around. Adopted from /1/

During different seasons there are different patterns of water stratification in a water body. During the cold period winter, stagnation takes place in a water body. This means that the coldest water stays close to freezed surface layers and water with the temperatures about from 3 up to the 5 °C stays at the bottom due to the specific phenomenon of water. This phenomenon is perceived that water has the highest density at 4,0 °C. /1./

Between the winter and summer the spring overturn comes. The highest layers are warmed up to 4.0 °C, stratification becomes unstable causing circulation. The temperature throughout the water body is mostly the same. /1./

When the summer arrives and the water temperature reaches the highest possible temperatures, the circulation loops can be found only in the upper part of a lake while the lower layers stay quite stable throughout all the season. The temperature conditions of water in deep lakes during summers are featured by the presence of a sharp change of temperature. Upper parts could be warmed up to, for example 31 °C, while the lower ones stay cooled. This temperature is about 10 °C. This temperature pattern is called summer stagnation. /1./

During the autumn, lakes start to lose heat from surface by evaporation and back radiation, and after reaching the temperature of 4 °C and having upper layers freezed, the winter stagnation comes again (autumnal overturn). /1./

A lake should be deep enough to have satisfactory thermal stratification all year round. The sufficient depth should be at least 12 meters. Due to gravity forces and the thermal stratification, cold water in deep water bodies remains undisturbed close to the bottom layers of water, thus allowing to use that water directly for cooling. /1./

Open loop systems

Open loop systems deriving energy from surface water bodies is like an unlimited cooling tower without the necessity of constant fan operation or regular maintenance. Water is taken from one point of the water body. Energy contained in this water is somehow extracted usually by means of a heat exchanger and discharged in another point. /3./ The operational principle of this type of the system is similar to the system based on ground water wells and presented in the Figure 2, but instead of the "Ground level" it should be named "Surface water". The heat exchanger plays the same role, transferring energy from the water in a natural water body to the heat carrier in the customer's part of the system and preventing the direct contact between both.

Several specific factors should be taken into account during the design process of open-loop systems. The first one is water quality which in the worst cases is causing corrosion, fouling of heat exchangers or even blockade (clogging). The second one is an adequate quality of available water. It could happen so that the amount of water in the available water body is not sufficient to satisfy demanded heat or cooling loads. Open loop systems usually demand the highest pumping load compared to any other kind of a system. Nonetheless in an ideal case, operational costs of an open loop application could be the lowest among all the systems utilizing geothermal energy in the surface water bodies. /5./

The advantages of the open loop configuration are the following: simple design, less drilling needed and higher efficiency due to absence of extra pipe lengths compared to closed loop systems. One of the most critical disadvantages is that pump sizing is too critical — oversizing or poor control results in high inefficiency rates. /5./

Closed loop systems

A closed loop system is shown in Figure 12. Closed loop systems are more preferable compared to open-loop ones. The first advantage is that fouling of the system due to dirty water from the surface water body is insignificant, because untreated lake or river water contacts with the system by means of closed loops. Inside the system, treated water or antifreeze solutions circulate. The second advantage is eliminating elevation pressure from the lake surface, thus reducing electrical expenses for pumping. /5./

Disadvantages are that a too low temperature difference between the supply and return pipes of a closed loop is available and the possibility of damaging the underwater network if it is placed somewhere in a public water body, for example boat anchors. If water in a water body is too foul, for example water is murky due to peat, some problems will arise, and the performance of the system in this case is lowered because of a worse heat conduction ability of the pipes because of deposits over the pipes. /5./

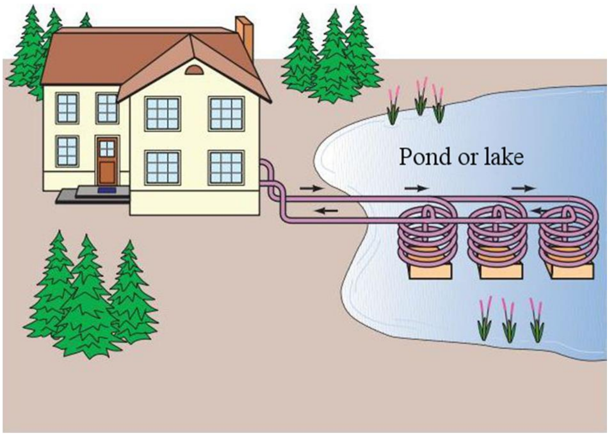


FIGURE 12. Closed loop system deriving energy from surface water body /9/

The layout patterns of closed loop systems can be the same as similar patterns used in ground loops mainly in horizontal and spiral patterns. The difference is that the first one has water as a surrounding medium as water, the second one has the solid ground. Having no need for groundworks, these types of systems significantly reduce the costs of installation. The type of the outer side of the open or closed loops (either this is ground or water) also affects the whole performance of the system. Due to a much higher coefficient of the heat transfer between the submersed pipes of closed loop and water compared to the coefficient of the heat transfer between the pipes of a ground loop, much shorter pipe lengths are required.

7 TRANSFERRING ENERGY FROM GROUND TO AIR

There are some ways which make the transition of energy derived from the ground possible. Systems based on these different ways of power transition can be divided into two kinds: direct systems and indirect systems. This division is based on whether there is or not direct contact between air and water.

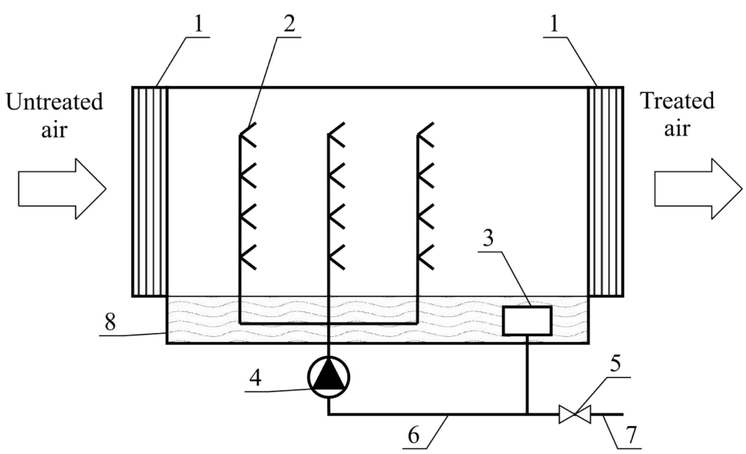
Different systems have their own benefits and disadvantages, different requirements of approach in designing, planning, choosing and maintaining equipment.

7.1 Direct systems

Direct systems mean that there is direct contact between treated air and ground water. These processes are called direct injection humidification. This imposes special limitations over the possibility to utilize such kind of a system, which is discussed below.

The most major limitation is that, it is possible to utilize these kinds of systems only in the processes of air cooling. This limitation is obvious because if cold air with temperature less the 0 °C is heated by means of a direct injection of water, this will cause icy fog, and icing will take place. The further use of the systems will be impossible. /15./

The principles of direct systems are mainly realized in spray chambers or direct injection chambers. A typical spray chamber consists of a water supply system with ordinary supply, return and circulation lines, pumps, valves and water-jets. Due to the water-jets and high pressure of water, water is dispersed in the chambers thus creating a spray region or fog. As shown in the Figure 13, the spray chamber is based on adiabatic process. The constant amount of water is circulated inside the system, and no energy is delivered from the outside of the system. Only a small amount of evaporated or entrained water needs to be compensated by means of the filling pipe. /15./



1 — separator,
2 — water-jet,
3 — water filter,
4 — circulation pump,
5 — shut-off valve,
6 — circulation pipe,
7 — filling pipe,
8 — water tray.

FIGURE 13. Example of typical spray chamber

7.2 Air treatment processes in direct systems

Depending on the temperature of supplied water, it is possible to achieve different processes of air treatment. By means of direct contact of air and water, it is also possible to humidify or dehumidify air. Those processes are presented in Figure 14.

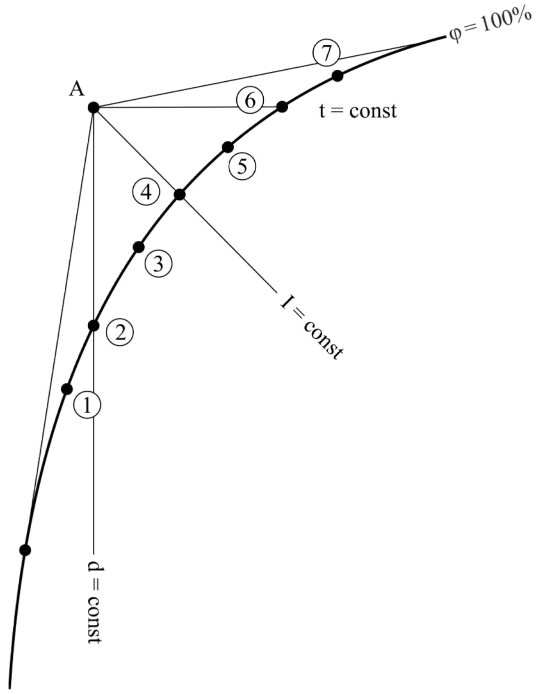


FIGURE 14. Process of air treatment by means of water.

According to Figure 14, the type of the process of air treatment depends on water temperature. By regulating the temperature of treating water, it is possible to dehumidify, cool, humidify or heat air. Those processes can be held seperately or together. Thus, for the point 1 air is being cooled and dehumidified, for the point 2 — cooled with constant moisture content, 3, 4, 5 — cooled and humidified on different extent, 6 — humidified with constant temperature, 7 — humidified and heated. It is impossible to hold the air treatment process of air out of the zone, restricted by the line of the maximum moisture content (φ = 100 %) and tangents to the same line of the maximum moisture content drawn from the initial point, describing the air parameters.

The necessity of utilization of drinkable water due to direct contact with air forces to make enough deep water wells despite the deeper borehole is the higher construction costs and the higher obtained temperature of supply water in the case of the direct utilization of ground water. This is the first disadvantage of direct systems. /15./

The second disadvantage is too high required water flow derived from water wells per each kilowatt of cold or heat due to the small temperature difference of water coming to the spray chamber and leaving it. This temperature difference is about 2–4 °C. This will entail too high requirements for water wells. Water wells should be productive enough, and the distances between each water well should be enough to prevent mutual thermal interference or depletion of ground water level. When the ground loops are used, this entails increasing the sizes of ground loops which, similarly, increases the costs of system installation. All these can be avoided by means if the closed-loop systems. /15./

7.3 Indirect systems

An indirect system means that there is no direct contact between treated air and ground water. In the indirect systems it is possible either to cool or to heat air. The difference of indirect systems from direct ones is that these systems can be used for heating supply air during cold seasons. The principal scheme of the indirect system is presented in Figure 15. The positions are the following 1 — supply water pipe (whether water from production well or cooled or warmed water from ground loop), 2 — return pipe (discharge utilized water into injection well or connection pipe of the ground loop). /15./

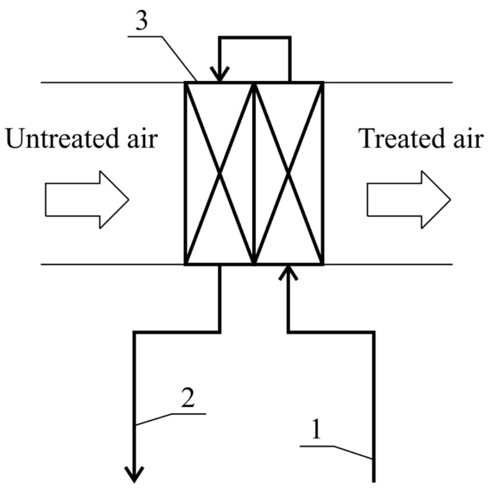


FIGURE 15. Principal scheme of indirect system.

The main advantage of the indirect systems is that required flow rates are much lower than in the direct system. In the direct systems, water and air are in contact only from the moment water is sprayed by means of water-jets until the moment the dispersed water reaches the water tray. In the indirect systems, it is possible to regulate the flow rate, mainly by significantly decreasing it. By means of this regulating, it is possible to achieve the highest possible temperature difference, reaching this temperature difference from 8 up to 10 °C. This temperature difference can be higher respective to the lowest required flow rate. /15./

7.4 Air treatment processes in indirect systems

The processes of air treatment in the indirect systems are the same as in the direct systems (Figure). The only difference is if condensation of moist from air is presented, attention to the collection and removing condensation from the system should be paid.

7.5 Combined systems

Combined systems are usually used in big systems when it is impossible to obtain the required amounts of ground water with the required temperature. The combined systems are implied for air cooling. In these systems cooling is produced by means of cooling machines alongside with cold derived from the ground. The combined systems mainly can be divided into two groups: systems with precooling of air and systems with precooling of ground water. /15./

7.6 Systems with precooling of air

The combined systems with the precooling of air (Figure 16) are used when the amount of available ground water is not enough to satisfy required powers. In this case the temperature of water should also be quite low. /15./

In that system the supply air is cooled by the supply water 1, carrying energy derived from the ground in a precooler 2 (the 1rst cooling stage). After the precooler 2, lukewarm water is collected in the water tank 3. From the water tank 3, the lukewarm water can be recycled for cooling of condenser of a heat pump 5 or just discharged whether in sewerage system 7, or this water can be returned to the ground by means of injection well 6 (or connection pipe to the ground loop). The following cooler (the 2nd cooling stage) is connected to the heat pump. /15./ The other references from the picture are the following: 4 — pump, 8 — evaporator of the heat pump, 9 — cooler of the 2nd stage, 10 — shut-off valve, 11 — heat pump circulation pipes, 12 — overfill pipe

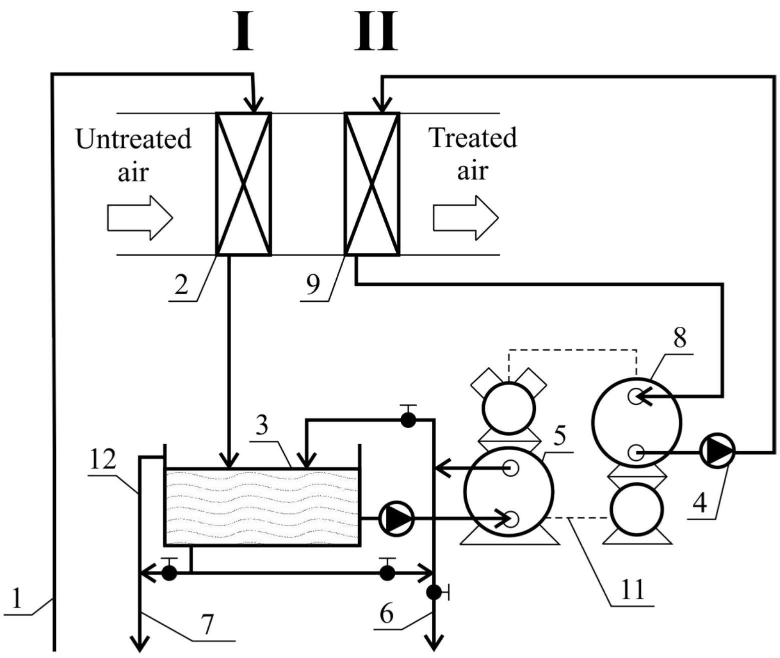


FIGURE 16. Principal scheme of combined system with precooling of air. Adopted from /15/

7.7 Systems with precooling of ground water

Systems with the precooling of ground water are used when there are enough volumes of ground water but its temperature is too high for direct application. The principal scheme of the system is depicted in Figure 17.

Supply water 3 (from production well or ground loop) is cooled by means of the evaporator of the heat pump 5. The cooled water passes through the cooler 6. After taking heat from the condenser of the heat pump 4, warm water is discharged in the injection well 1 (or connection pipe of a ground loop) or in the sewerage system 2. The required capacity of the cooling machine is determined only by the additional temperature drop of ground water. /15./

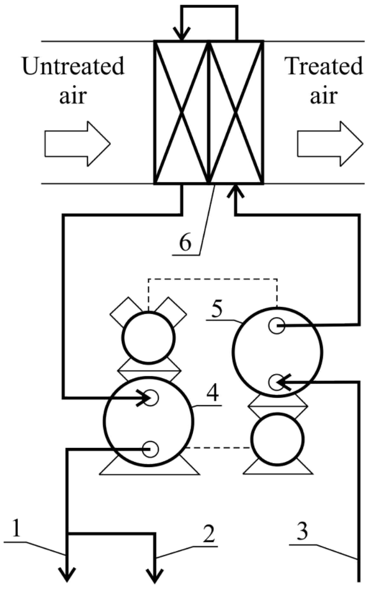


FIGURE 17. Principal scheme of combined system with precooling of ground water. Adopted from /15/

8 CASE STUDY

In this chapter a certain building will be observed. The building named N-building is an office building, in the Mikkeli University of Applied Sciences campus. Offices are located in the building. One part of the building has two floors, the other part has three floors. The total area of the building is about 3800 m².

Data obtained from an automation system of an air handling unit of the building are used for the analysis. Further the analyzed data will be compared with the data gotten from a similar virtual air handling unit.

The problem studied in this thesis, that system gives the possibility to recover some energy for heating air in the winter time, replacing an ordinary primary heating coil. Similarly this system gives us a possibility to utilize free ground cooling energy to cool intake air in the summers. Utilizing the heat recovery unit all the same increases the total energy efficiency of the air handling unit.

Outdoor supply air is firstly treated by means of an air coil, referred later as ground-to-air coil. This coil is directly connected to ground loops. The system is based on nine vertical boreholes. The depth of each borehole is about 200 meters. The ground loops are placed in boreholes. The system of transferring heat from the ground to air is indirect.

The temperature of circulated through ground loops water is almost the same throughout the year. So, in the summers it is possible to precool the intake air to some extent, in the winters it is possible to preheat the intake air. After this, the coil on the ordinary heat recovery wheel is installed for the extracted energy from exhaust air and heating intake air. Being heated in the heat recovery unit, air is proceeded further and finally heated in the second coil where air could be heated up to the desired temperature in the winters.

Firstly it seems that it is possible to save more energy compared to the traditional systems utilizing only the heat recovery unit. The energy efficiency of a recovery unit should be also taken into account. Having supply air with higher temperature decreases total heat recovery ratio of a heat recovery unit. This requires closer consideration because the derived energy from ground decreases the total energy efficiency of the heat recovery unit, thus some kind of equilibrium should be found to make such a system more energy efficient.

8.1 Air handling unit in case

The ventilation of the building is realized by means of two air handling units TK2 on the first and second floors and TK3 (public places). Air handling units are equipped with heat recovery units: TK2 — rotary, TK3 — plate.

In this work only TK3 is considered. The principal scheme of the air handling unit TK3 is presented in Figure 18. For the studied period of time, the air handling unit TK3 is on twenty four hours a day. The supply air flow rate is regulated according to demand and varies from 200 l/s up to 350 l/s. The exhaust air flow rate is from 230 l/s up to the 350 l/s. The supply air temperature varies from 19 up to 21 °C. The exhaust temperature varies from 22 up to 24 °C.

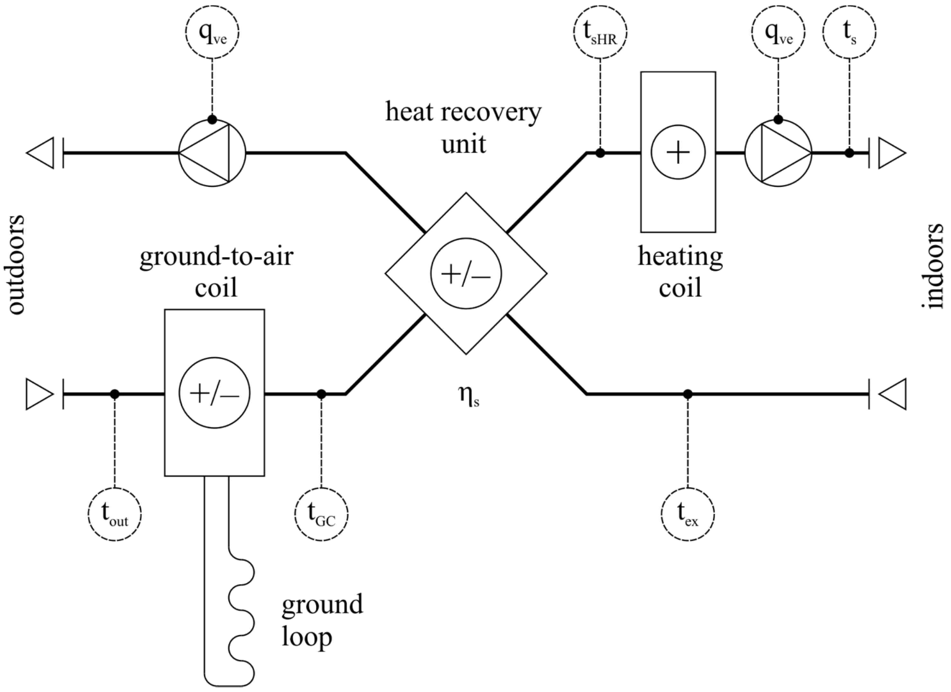


FIGURE 18. Principal scheme of the air handling unit in case

8.2 Virtual air handling unit

The virtual air handling unit is similar to the air handling unit in case. The only difference is that there is no ground-to-air coil with ground loops. The principal scheme of a virtual air handling unit is presented in Figure 19. Such the arrangement of air handling units is quite common.

8.3 Initial data

As it was said, initial data are obtained from the automation system of the air handling unit. Measurements are made and recorded every hour. Data are presented from 13 December 2012 until 1 February 2013. Data are presented in Excel sheets. Available initial data is shown in Figure 19 in dashed lines. The example of initial data for one day is presented in Appendix 1.

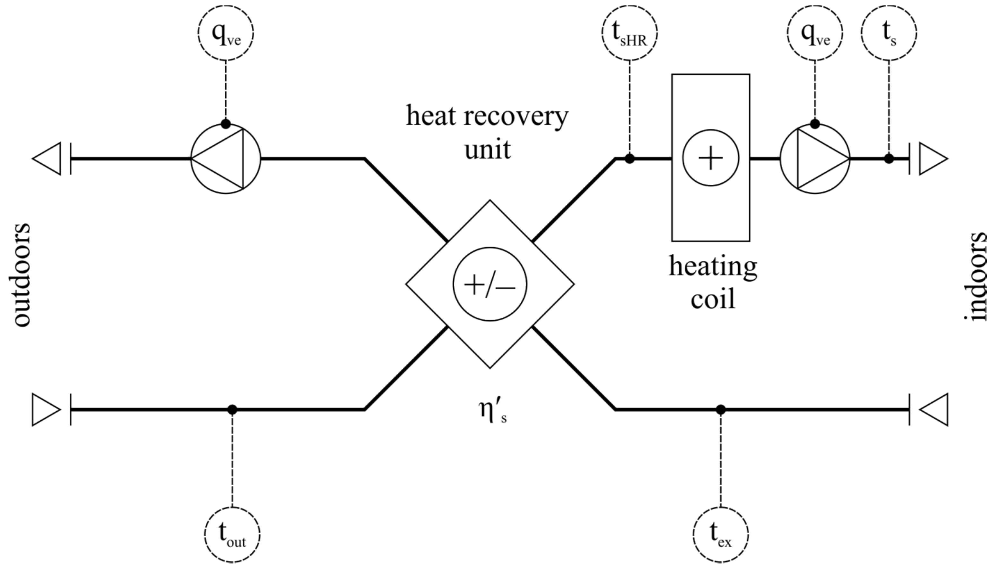


FIGURE 19. Principal scheme of the virtual air handling unit

8.4 Accuracy and consumptions

Everyone should reasonably evaluate the presented data and results. It is needed to be taken into account that stationary measurement devices inside the air handling unit have their own inaccuracies, different inaccuracies due to improper choosing or the impossibility due to the lack of space of place for sensor installation should also be considered. During the following calculations the consumption is made so that in fans the air is heated up at 0,5 °C.

8.5 Calculations for the AHU in case

The following calculations are made for every hour of registered data. The utilized energy in ground-to-air coil Q_{GC} is calculated from /1/

$$Q_{GC} = q_{vs} c_p \rho \left(t_{GC} - t_{out} \right) \quad (1)$$

where q_{vs} is the supply air volume flow rate, c_p is the specific air heat capacity, ρ is the density of air, t_{GC} is the supply air temperature after ground-to-air coil, t_{out} is the outdoor air temperature. The utilized energy in the heat recovery unit Q_{HR} is calculated from the equation /2/

$$Q_{HR} = q_{vs} c_p \rho \left(t_{sHR} - t_{GC} \right) \tag{2}$$

where t_{sHR} is the supply air temperature after the heat recovery unit. The utilized energy in the heating coil Q_{HC} is determined by means of /3/

$$Q_{HC} = q_{vs} c_p \rho \left(t_s - t_{sHR} \right) \tag{3}$$

where t_s is the supply air temperature, $t_s = t_s' - 0,5.$ The total recovered energy Q_{rec} is calculated from /4/

$$Q_{rec} = Q_{GC} + Q_{HR} \tag{4}$$

where Q_{GC} is the utilized energy in the ground-to-air coil, Q_{HR} is the utilized energy in the heat recovery unit.

Further, the total heat energy consumption is calculated for every period. Mainly the period is a week matched with a calendar week. There are short periods of a few days at the beginning and at the end of the data. The total consumption for every period is a sum of the total recovered energy for the very hour constituent this period.

8.6 Calculations for the virtual AHU

The calculations of the virtual air handling unit are based on the same initial data. Thus with some limitations allow to compare the system with ground-to-air coil to more traditional systems.

For comparising the actual results, we need to get some results from the virtual air handling unit. Due to the absence of ground-to-air coil in the virtual air handling unit, the temperature of air (coming to the heat recovery unit) will be different from the similar temperature in the air handling unit. Thus the temperature ratios differ from the original ones.

For further calculations the temperature ratios are needed. For calculating the data from the virtual air handling unit, the temperature ratios are supposed to be from 0,55 (minimum value for cross-flow heat exchanger according to /16/) up to 0,85.

The supply air temperature after the heat recovery t'_{sHR} unit is calculated from the equation /5/

$$t'_{SHR} = \eta'_s \left(t_{ex} - t_{out}\right) + t_{out} \tag{5}$$

where η'_s is the ensured supply air temperature ratio, t_{ex} is the exhaust air temperature before the heat recovery unit. The possible utilized energy in the heat recovery unit Q'_{HR} is determined by /6/

$$Q'_{HR} = q_{vs} c_p \rho \left(t'_{sHR} - t_{out}\right) \tag{6}$$

where t'_{sHR} is the supply air temperature after the heat recovery unit in the virtual AHU. The possible utilized energy in heating coil Q'_{HC} is calculated from /7/

$$Q'_{HC} = q_{vs} c_p \rho \left(t_s - t'_{sHR}\right) \tag{7}$$

To prevent the heat recovery unit from freezing in the exhaust side, norms restrict the minimum exhaust temperature after the heat recovery unit. For the current building this temperature is 0° /17/.

For calculating the temperature of exhaust air after the heat recovery, ratio R is determined from /8/

$$R = \frac{q_{vs}}{q_{ve}} \tag{8}$$

where q_{ve} is the exhaust air volume flow rate. The exhaust temperature ratio η'_e is calculated from the equation /9/

$$\eta_e' = R\eta_s' \tag{9}$$

The exhaust air temperature after the heat recovery unit t_{eHR} is calculated from /10/

$$t_{eHR} = t_{ex} - \eta_e'(t_{ex} - t_{out}). \tag{10}$$

The exhaust air temperature after the heat recovery unit should be bigger that 0° /17/. If $t_{eHR}' < 0°C$, the temperature ratios should be calculated once again by means of the equation /11/, where η_e'' is the corrected ensured exhaust air temperature ratio

$$\eta_e'' = \frac{t_{ex} - 0}{t_{ex} - t_{out}} \tag{11}$$

The corrected supply temperature ratio η_s'' is determined by means of /12/

$$\eta_s'' = \frac{\eta_e''}{R} \tag{12}$$

The corrected air temperature after the heat recovery unit t_{sHR}'' (with limitation of exhaust air temperature) is calculated by means of /13/

$$t_{sHR}'' = \eta_s''(t_{ex} - t_{out}) + t_{out} \tag{13}$$

The corrected possible utilized energy in the heat recovery unit Q_{HR}'' is calculated by means of the equation /14/

$$Q_{HR}'' = q_{vs}c_p\rho(t_{sHR}'' - t_{out}) \tag{14}$$

The corrected utilized energy in the heating coil Q_{HC}'' is estimated from the equation /15/

$$Q''_{HC} = q_{vs} c_p \rho \left(t_s - t''_{SHR} \right) \tag{15}$$

8.7 Example of calculations

Initial data for the example are presented in Table 1.

TABLE 1. Initial data for the example

	Outdoor temperature, t_{out}	Supply air volume flow rate, q_{vs}	Extract air volume flow, q_{ve}	Supply air temperature after the heat recovery unit, t_{sHR}	Supply air temperature, t_s	Extract air temperature, t_{ex}	Supply air temperature after the ground-to-air coil, t_{GC}
	°C	l/s	l/s	°C	°C	°C	°C
23.12.2012 10:00	-24,25	198,88	241,56	11,23	19,83	23,53	-4,79

Calculations for the AHU in case

Firstly, the utilized energy in the ground-to-air coil is calculated from the equation /1/

$$Q_{GC} = \frac{198,88}{1000} \cdot 1,0 \cdot 1,2 \cdot \left(-4,79 - \left(-24,25 \right) \right) = 4,64 \text{ kWh.}$$

The utilized energy in the heat recovery unit is found from /2/

$$Q_{HR} = \frac{198,88}{1000} \cdot 1,0 \cdot 1,2 \cdot \left(11,23 - (-4,79) \right) = 3,82 \text{ kWh.}$$

Further, the amount of utilized energy in the heating coil is determined from the equation /3/

$$Q_{HC} = \frac{198,88}{1000} \cdot 1,0 \cdot 1,2 \cdot \left(\left(19,83 - 0,5\right) - 11,23\right) = 1,93 \text{ kWh.}$$

The total recovered energy is calculated from the equation /4/

$$Q_{rec} = 4,64 + 3,82 = 8,46 \text{ kWh.}$$

Virtual AHU

η'_s is supposed to be 0,65. Firstly, the supply air temperature after the heat recovery unit is estimated from the equation /5/

$$t'_{SHR} = 0,65 \cdot \left(23,53 - \left(-24,25\right)\right) + \left(-24,25\right) = 6,81 °C.$$

Then the possible utilized energy in the heat recovery unit is calculated from the equation /6/

$$Q'_{HR} = \frac{198,88}{1000} \cdot 1,0 \cdot 1,2 \cdot \left(6,81 - \left(-24,25\right)\right) = 7,65 \text{ kWh}$$

and the possible utilized energy in the heating coil is estimated by means of /7/

$$Q'_{HC} = \frac{199,88}{1000} \cdot 1,0 \cdot 1,2 \cdot \left(19,83 - 6,81\right) = 3,12 \text{ kWh.}$$

From the equation /8/ ratio R is determined

$$R = \frac{198,88}{241,56} = 0,82.$$

Further the exhaust temperature ratio is calculated from the equation /9/

$$\eta'_e = 0,82 \cdot 0,65 = 0,53.$$

Making the estimation of the exhaust air temperature after the heat recovery unit according to /10/

$t_{eHR} = 23{,}53 - 0{,}53\cdot\left(23{,}53 - \left(-24{,}25\right)\right) = -1{,}79°C < 0°C,$ it becomes clear that the correction of the temperature ratios are needed. The correction for the exhaust temperature ratio is made according to the equation /11/

$$\eta''_e = \frac{23{,}53 - 0}{23{,}53 - \left(-24{,}25\right)} = 0{,}49.$$

Then, the corrected supply temperature ratio is determined basing on the equation /12/

$$\eta''_s = \frac{0{,}49}{0{,}82} = 0{,}60.$$

The corrected air temperature after the heat recovery unit is calculated from /13/

$$t''_{SHR} = 0{,}60\cdot\left(23{,}53 - \left(-24{,}25\right)\right) + \left(-24{,}25\right) = 4{,}42°C.$$

Finishing calculations, the corrected possible utilized energy in the heat recovery unit is estimated by means of /14/

$$Q''_{HR} = \frac{198{,}88}{1000}\cdot 1{,}0\cdot 1{,}2\cdot\left(4{,}42 - \left(-24{,}25\right)\right) = 6{,}84\,kWh.$$

and the same for the heating coil by means of /15/

$$Q''_{HC} = \frac{198{,}88}{1000}\cdot 1{,}0\cdot 1{,}2\cdot\left(\left(19{,}83 - 0{,}5\right) - 4{,}42\right) = 3{,}56\,kWh.$$

8.8 Calculated data

Calculations for the whole period are presented in Table 2 and Table 3. Calculated recovered and consumed heat is presented as a summary in the periods. In the calculations of the virtual air handling unit different temperature ratios were adapted. The temperatures ratio was taken, as said before, equally 0,55 and further 0,65, 0,75 and 0,85.

TABLE 2. Calculations for air handling unit in case

Dates			Air handling unit in case			
			Recovered energy, kW·h			Spent energy, kW·h
			ground-to-air coil, Q_{GC}	HR, Q_{HR}	sum, Q_{rec}	heating coil, Q_{HC}
2012	13.12-16.12	4 days	203,74	333,52	537,26	172,49
	17.12-23.12	Week 1	522,55	670,76	1193,31	364,85
	24.12-30.12	Week 2	439,41	676,03	1115,44	377,38
2012-2013	31.12-06.01	Week 3	273,79	689,55	963,34	399,33
2013	07.01-13.01	Week 4	408,72	711,99	1120,71	373,82
	14.01-20.01	Week 5	478,00	727,79	1205,79	379,71
	21.01-27.01	Week 6	448,53	700,85	1149,39	380,73
	28.01-01.02	5 days	184,45	458,57	643,02	278,04

TABLE 3. Calculations for the virtual air handling unit

Dates		Virtual air handling unit							
		Recovered energy, kW·h	Spent energy, kW·h	Recovered energy, kW·h	Spent energy, kW·h	Recovered energy, kW·h	Spent energy, kW·h	Recovered energy, kW·h	Spent energy, kW·h
		$\eta'_s = 0,55$		$\eta'_s = 0,65$		$\eta'_s = 0,75$		$\eta'_s = 0,85$	
		HRU	heating coil	HRU	heating coil	HRU	heating coil	HRU	heating coil
13.12-16.12	4 days	442,55	267,20	523,01	186,74	603,48	106,28	683,94	25,81
17.12-23.12	Week 1	951,06	607,10	1105,66	452,49	1182,02	376,14	1215,03	343,13
24.12-30.12	Week 2	920,21	572,61	1087,01	405,82	1227,43	265,40	1323,86	169,07
31.12-06.01	Week 3	889,56	473,10	1051,30	311,36	1213,04	149,62	1374,78	9,64
07.01-13.01	Week 4	945,40	549,13	1117,29	377,24	1282,61	211,92	1425,24	72,66
14.01-20.01	Week 5	984,36	601,14	1133,15	452,34	1263,01	322,48	1385,10	200,41
21.01-27.01	Week 6	945,85	584,27	1117,82	412,30	1289,06	241,07	1442,89	87,23
28.01-01.02	5 days	592,20	328,86	699,87	221,18	807,55	113,51	915,22	11,19

8.9 Results

The graphical representation of recovered energy in the air handling unit in case is represented in Figure 20, Figure 21 and Figure 22 for every period. Outdoor temperatures are added for the sake of clearness.

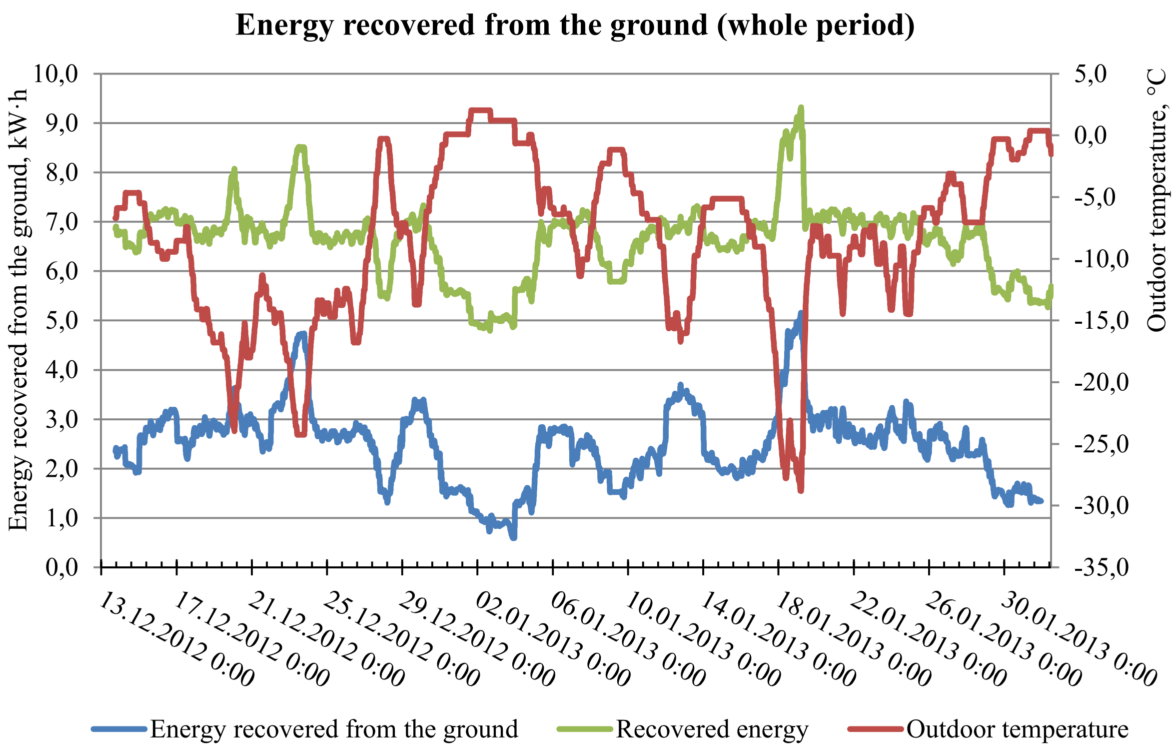


FIGURE 20. The studied period

The basic parameters for the comparison are recovered energy and the effectiveness of heat recovery units and the heating coil connected to ground loops. The recovered energy consists of the energy recovered from the ground and the energy recovered from an extract air by means of the heat recovery unit for the air handling unit in case. For the virtual air handling unit, the recovered energy consists only of the energy derived from an exhaust air in the heat recovery unit.

When analyzing the results, it is obvious that the air handling unit in case has almost the same amounts of recovered energy as a similar virtual air handling unit with only the heat recovery unit and the heating coil (supply air temperature ratio of heat recovery unit $\eta_s'' = 0,65$).

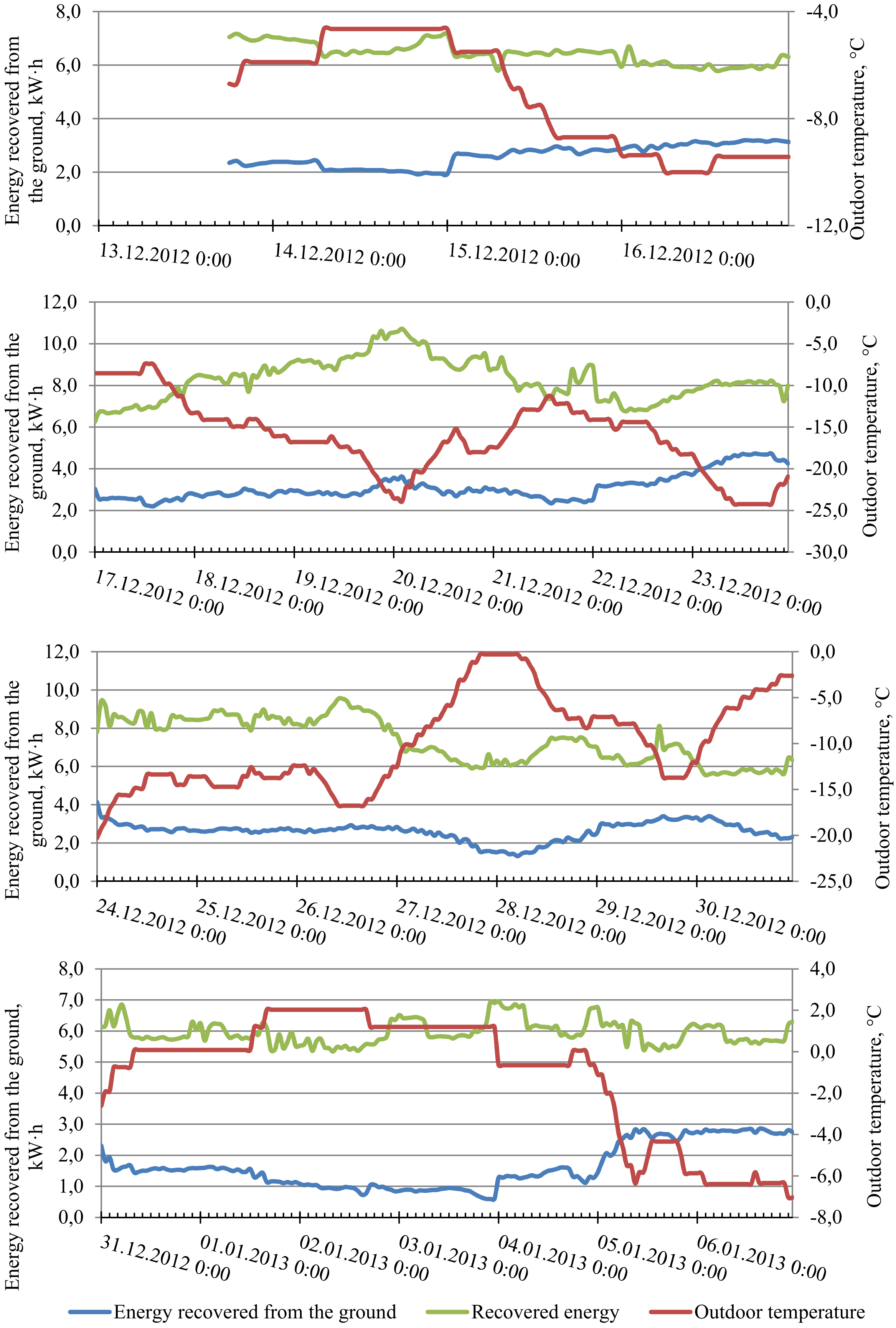


FIGURE 21. Weekly periods (14 Dec 2012 — 6 Feb 2013)

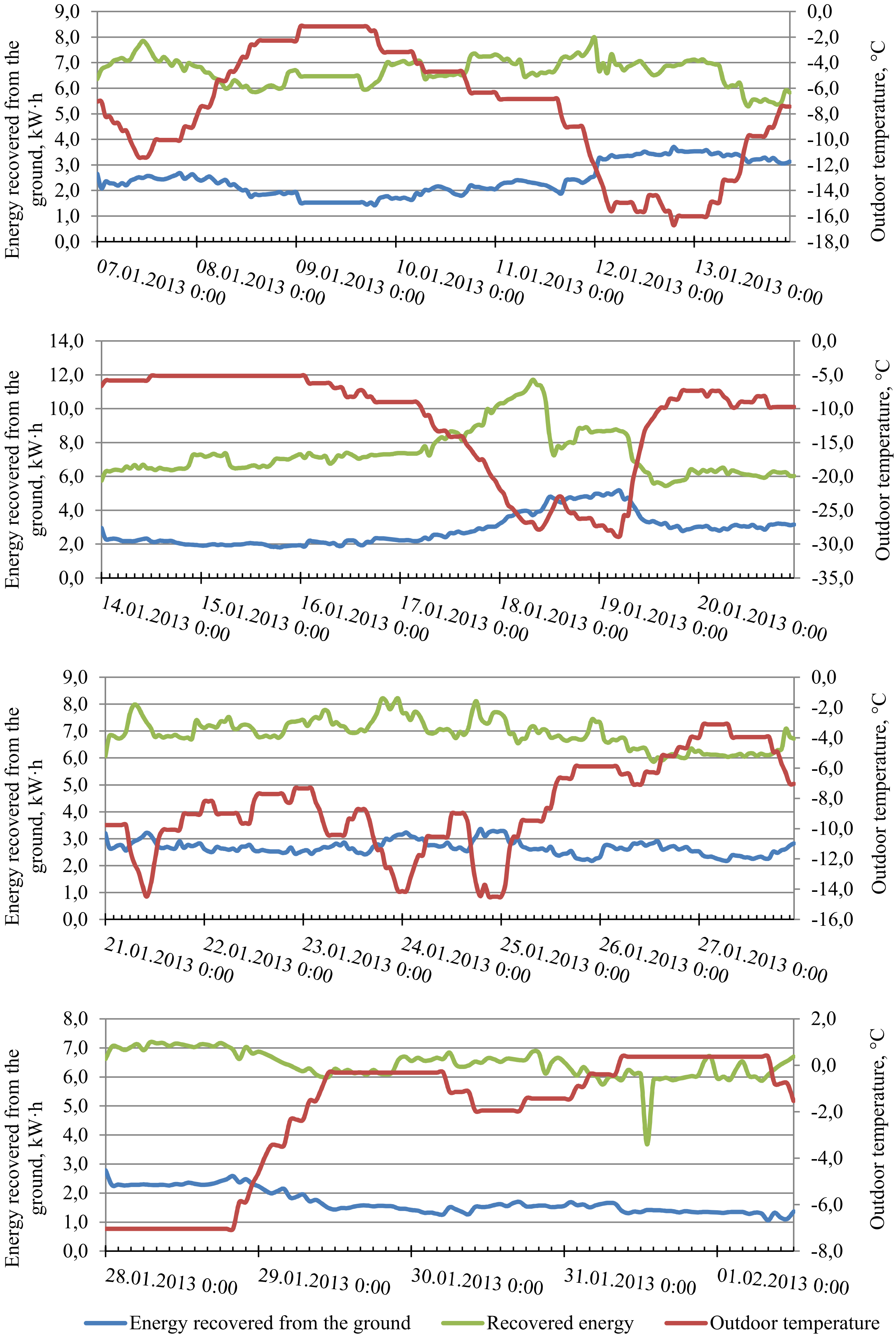


FIGURE 22. Weekly periods (7 Jan 2013 — 1 Feb 2013)

Having increased the supply air temperature ratio from about $\eta_s'' = 0,65$ for the virtual air handling unit, the situation only worsens. In this case, it is possible to recover more energy from the extract air only by means of the heat recovery unit. Thus, in this case the understudied system (ground-to-air coil, ground loop and heat recovery unit) loses in energy recovery. For the virtual air handling unit with heat recovery systems, it was discovered that with the ensured temperature ratio $\eta_s'' = 0,75,$ it is possible to recover more energy by about 10 % and with the ensured temperature ratio $\eta_s'' = 0,85,$ it is possible to recover more energy by about 20 % (Table 4). Too big deviations in certain periods can be explained by inconstant outdoor temperature roughly estimated as an average outdoor temperature in each period. Positive values are for the cases when the virtual AHU recovers (or saves) more energy. Negative values are for the cases when the AHU in the case recovers (or saves) more energy.

In the case when the supply air temperature ratio of the virtual air handling unit is about 0,55, the air handling unit in the case recovers about 20 % more energy.

Concerning the energy spent for the heating coil, it is difficult to make certain conclusions. For ensured the supply air temperature ratio in the virtual air handling unit about $\eta_s'' = 0,65,$ the spent energy for the heating coil is almost the same as in a real case. Having the ensured supply air temperature ratio of $\eta_s'' = 0,55,$ the virtual air handling unit requires about 30 % more energy for heating air by means of the heating coil. Having the ensured supply air temperature ratio of $\eta_s'' = 0,85,$ the virtual air handling unit saves about 70 % more energy for heating air by means of the heating coil (Table 5).

Based on the data and discussion, the following conclusion can be drawn: the investigated system is close to being equivalent to a more traditional system based only on air-to-air heat utilization. Thus, under the certain investigated outdoor conditions the system in the case is almost a full equivalent of the system utilizing only air-to-air heat recovery. This equality is achieved only if the heat recovery ratio is ensured to be 0,65 or more for the traditional system based on air-to-air heat utilization. Getting the higher value of the temperature ratio only saves more energy for the heating coil and allows to extract more energy from exhaust air compared to the system based the on ground loops.

TABLE 4. Relations of corresponding energy recovered in the air handling unit in case and recovered energy in the virtual air handling unit

	Average outdoor temperature for the period	η_s'	%			
			0,55	0,65	0,75	0,85
13.12-16.12	-7,2	4 days	-17,6	-2,7	11,0	21,4
17.12-23.12	-16,1	Week 1	-20,3	-7,9	-1,0	1,8
24.12-30.12	-9,9	Week 2	-17,5	-2,6	9,1	15,7
31.12-06.01	-1,1	Week 3	-7,7	8,4	20,6	29,9
07.01-13.01	-7,8	Week 4	-15,6	1,0	12,6	21,4
14.01-20.01	-11,8	Week 5	-18,4	-6,4	4,5	12,9
21.01-27.01	-8,5	Week 6	-17,7	-2,8	10,8	20,3
28.01-01.02	-2,1	5 days	-7,9	8,1	20,4	29,7
	Average for the whole period		-15,3	-0,6	11,0	19,2

TABLE 5. Relations of corresponding energy spent in the air handling unit in case and energy spent in the virtual air handling unit

	Average outdoor temperature for the period	η_s'	%			
			0,55	0,65	0,75	0,85
13.12-16.12	-7,2	4 days	-35,4	-7,6	38,4	85,0
17.12-23.12	-16,1	Week 1	-39,9	-19,4	-3,0	6,0
24.12-30.12	-9,9	Week 2	-34,1	-7,0	29,7	55,2
31.12-06.01	-1,1	Week 3	-15,6	22,0	62,5	97,6
07.01-13.01	-7,8	Week 4	-31,9	-0,9	43,3	80,6
14.01-20.01	-11,8	Week 5	-36,8	-16,1	15,1	47,2
21.01-27.01	-8,5	Week 6	34,8	-7,7	36,7	77,1
28.01-01.02	-2,1	5 days	-15,5	20,4	59,2	96,0
	Average for the whole period		-21,8	-2,0	35,2	68,1

Comparing the certain system with ground loops and a traditional system with only the heat recovery unit, it becomes clear that the equipment is the same (mainly considering only the heat recovery unit), but the system in case has had additional expenditures aroused from needed ground work and arranging ground loops, needed electricity and service for the additional equipment. The price of the equipment placed in a technical room are the same in both cases, but the investigated system required additional costs for additional air heat exchanger connected to the ground loops and arranging the ground loops. Possible money saving in the equipment dimensioning is also doubtful, because the equipment is usually dimensioned for the most critical conditions (in the system in case the heating coil should be able to provide the full needed temperature rise in the case if the ground loops breakdown and the ground-to-air coil is switched off).

Taking into the account that in practice the actual average value for heat recovery units is about 0,7-0,8 for the system with only the heat recovery unit, it is shown that the understudied system is unprofitable. According to the evaluated data from Tables 5 and 6, in the same outdoor temperature conditions and running modes of the system, it could have been possible to gain energy recovery by 11,0 % more in average and saving energy for the heating coil by 35,2 % more in average for the studied period (for temperature ratio 0,75), if the system was based only on air-to-air heat recovery.

The lower effectiveness of the heat recovery unit in the studied system is explained due to the lower temperature difference, thus allowing the smaller amount of heat transfer between the supply and exhaust air. The smaller temperature difference is gained due to presented preheating in the ground-to-air coil. During the studied period, the temperature ratio of the ground-to-air coil and heat recovery unit together was in the following range: 0,53…0,75 with the mean value of 0,65 (steps for calculating mean value are hours).

Drawing the final conclusion, the heat recovery unit is not utilized for the full capacity and this results in the lower efficiency of the heat recovery unit in studied system compared to a system with only heat recovery without preheating by means of ground energy. Less energy is extracted from exhaust air, thus resulting in higher energy demand for the heating coil.

9 DISCUSSION

As a result of the research work matters concerning the background of the topic were clarified and discussed. Further a certain case study was observed and analyzed. The studied system can be met quite seldom, so some questions over its effectiveness were arisen. According to the available statistical data on the operation of the certain air handling unit, analysis of an operation was made.

However, the analysis is not enough. As was stated in the aims of this work, the studied system operates in two certain states: winter and summer. In this work it was possible only to analyze the winter mode, when the intake air is being heated up by means of a ground-to-air coil. The heat carrier in the loop transfers energy from the ground to the air by means of a ground loop (between ground and heat carrier), the distribution network and ground-to-air coil (between heat carrier and air). Further analysis for summer and longer, repeatedly iterative periods should be made for more exact results.

The results obtained allow to state that the system studied with the ground loop is energetically equal in winter time to a more popular system based only on heat recovery unit, if the supply air temperature ratio of that heat recovery unit is possible to ensure equal at least to 0,65.

The gain in saving energy (put it differently, recovered free energy) is only visible compared with the traditional system with the ensured supply air temperature ratio η_s' less than 0,65 in the winter time operation. Otherwise if the ensured supply air temperature ratio of a compared traditional system is more than 0,65, there are no gains in any energy aspect. The studied system loses in effectiveness to a more traditional system without the direct utilization of ground energy from 10 % (for ensured supply air temperature ratio of 0,75 for the all period) up to the 20 % (for ensured supply air temperature ratio of 0,85 for the all period) in the aspect of the energy recovered. In the aspect of the energy spent for heating lukewarm air, the system studied consumes more energy from 30 % (for ensured supply air temperature ratio of 0,65 for all period) up to 70 % (for ensured supply air temperature ratio of 0,85 for all period).

During the analysis of this thesis work, it was discovered that the system studied is an equivalent to more traditional systems in the aspects of energy gains, spendings and savings for the winter operation mode. Under certain conditions, the system studied can bring power gain, but under other conditions the system loses in energy aspects compared to more traditional systems. The system studied shows the maximum power gains (15 % higher in energy extraction from the ground and exhaust air, 20 % lower amount of energy for heating air) only if this system could be replaced by a system with only the heat recovery unit with the lowest possible temperature ratio according to EN-308 $(\eta_s' = 0,55)$. In practice the temperature ratios of single heat recovery units are higher than EN-308 minimum, thus destroying any power gain of the system in the case comparing to a common system with only the heat recovery unit (for average probable temperature ratio of 0,75 for the same period and other conditions, a more common system could provide 10 % more in energy extraction and 35 % for saving energy for air heating). Similarly, concerns with additional equipment and ground work play their own roles and are taken into account.

It was shown that the system studied can have the same effectiveness as traditional systems. In this work, analysis was made only concerning the aspects of recovered and spent energy, other aspects should also be taken into account. Those aspects are: costs of groundworks, costs of installing and running a ground loop, energy gains in the summer mode operation. It can happen that the arrangement and running costs of ground installations will be much higher than the costs of energy for the whole lifecycle of a system which one would pay without the utilization of ground energy.

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Example of available initial data for one day of the whole period

	Date	Outdoor temperature, t_{out}	Supply air volume flow rate, q_{vs}	Extract air volume flow, q_{ve}	Supply air temperature after the heat recovery unit, t_{sHR}	Supply air temperature, t_s	Extract air temperature, t_{ex}	Supply air temperature after the ground-to-air coil, t_{GC}
		TE00	TK03-FE10	TK03-FE30	TK03-TE02	TK03-TE01	TK03-TE30	MLV01-TE04
		°C	l/s	l/s	°C	°C	°C	°C
Saturday	19.01.2013 0:00	-27,29	200,60	241,55	10,61	19,79	23,93	-6,68
	19.01.2013 1:00	-27,29	197,55	241,86	10,64	19,80	23,90	-6,76
	19.01.2013 2:00	-27,99	197,30	241,92	10,61	19,80	23,89	-6,88
	19.01.2013 3:00	-27,99	197,54	241,49	10,48	19,68	23,88	-7,20
	19.01.2013 4:00	-28,80	196,53	242,00	10,42	19,69	23,86	-7,20
	19.01.2013 5:00	-28,80	197,22	240,68	10,55	19,73	23,85	-7,04
	19.01.2013 6:00	-25,76	196,89	240,44	11,02	20,13	23,90	-6,09
	19.01.2013 7:00	-25,76	200,95	240,01	10,87	19,66	23,90	-6,14
	19.01.2013 8:00	-21,01	200,74	239,42	11,94	19,44	23,97	-2,99
	19.01.2013 9:00	-18,33	198,45	240,71	12,51	19,83	23,84	-1,54
	19.01.2013 10:00	-15,71	200,56	239,13	12,77	19,86	23,78	-0,91
	19.01.2013 11:00	-13,24	218,39	281,09	13,02	19,80	23,62	-0,40
	19.01.2013 12:00	-12,20	228,27	303,32	13,29	19,95	23,48	-0,20
	19.01.2013 13:00	-11,37	240,04	318,77	13,48	19,58	23,32	0,27
	19.01.2013 14:00	-10,44	248,18	337,67	13,69	19,84	23,23	0,45
	19.01.2013 15:00	-9,82	255,26	345,24	13,67	19,73	23,16	0,50
	19.01.2013 16:00	-9,82	256,58	345,97	13,66	19,59	23,07	0,69
	19.01.2013 17:00	-8,59	265,76	345,44	13,55	19,58	23,05	0,69
	19.01.2013 18:00	-8,59	265,56	345,24	13,55	19,72	22,99	0,84
	19.01.2013 19:00	-8,59	265,29	343,96	13,66	19,87	23,00	1,01
	19.01.2013 20:00	-7,35	278,95	342,65	13,35	19,61	22,96	0,94
	19.01.2013 21:00	-7,35	282,25	343,36	13,29	19,66	22,94	1,07
	19.01.2013 22:00	-7,35	280,09	342,66	13,44	20,34	22,99	1,25
	19.01.2013 23:00	-7,35	280,71	342,00	13,53	20,35	23,01	1,52